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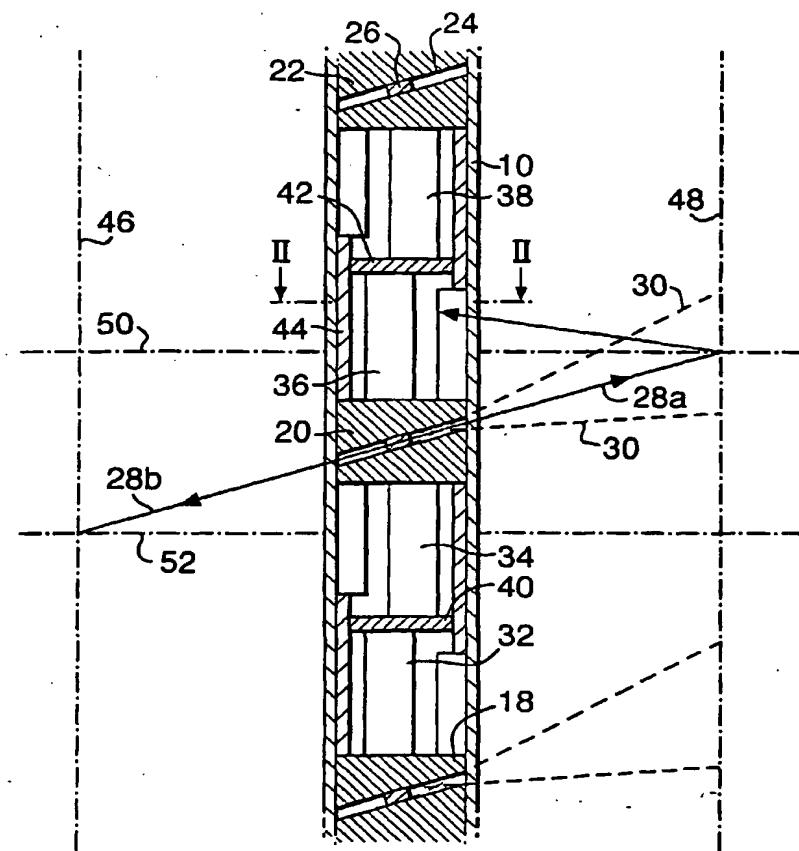
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*[Continued on next page]*

## (54) Title: LEVEL AND DENSITY MEASUREMENT USING GAMMA RADIATION



(57) Abstract: Apparatus for determining the density profile of a medium comprises a vertically disposed elongated member of a material transparent to  $\gamma$ -radiation containing a plurality of sources of collimated beams of  $\gamma$ -radiation of characteristic energy level below 100 keV and, for each beam, detector shielded from the sources by material transparent to the radiation. Each collimated beam is directed to irradiate a region external to said elongated member, and the detector associated with that beam is disposed to detect radiation scattered from said region by the medium.

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## LEVEL AND DENSITY MEASUREMENT USING GAMMA RADIATION

This invention relates to level measurement and in particular to apparatus for determining boundaries between phases, e.g. oil and water, or oil and gas, in a medium. The location of boundaries can be found by monitoring the variation in density of the medium, i.e. by 5 determining its density profile. The invention utilises ionising radiation to detect the differences in density.

It has been proposed in WO 00/22387 to measure the density profile of a medium by providing an axially distributed array of sources of ionising radiation, e.g.  $^{241}\text{Am}$  which is a source of low energy  $\gamma$ -radiation, to give collimated beams of said radiation and an axially 10 distributed array of detectors disposed so that the medium under study extends between the sources and the detectors. By monitoring the radiation received by the detectors, the amount of radiation absorbed by the medium from each beam can be determined and so variations in the medium density can be detected. The arrangement of WO 00/22387 employed two, or preferably three, tubes of a radiation transparent material, such as titanium, disposed 15 substantially vertically but spaced apart in the medium. One tube is provided with a vertical array of sources, while a vertical array of detectors is disposed in the other tube or tubes. The length of the beam of radiation, i.e. the distance from the source to detector, was preferably in the range 3 to 15, particularly 5 to 10, cm as this enables the apparatus to be introduced into a vessel, e.g. an oil separator, through a single port. Generally the port needs to have a 20 diameter of 10 cm or more, especially if a system having two detector columns is employed.

In some cases it has been found that the vessel lacks a port of sufficient size to accommodate apparatus of the above type at the location where it is desired to monitor the medium.

In the present invention, the sources and detectors are associated with a single 25 elongated member and so, providing the sources and detectors are not too large, the elongated member can have a diameter significantly less than the maximum cross section dimension of the aforesaid two or three tube system, and so may be inserted through a smaller port, for example a port of diameter about 50 mm or less. Whereas the aforesaid system of WO 00/22387 relied upon absorption of radiation by the medium between the source and detector, 30 the system of the present invention relies upon back-scattering of the radiation.

US 4661700 describes a well logging sonde which utilises back-scattering and employs a single source of radiation and a pair of detectors axially displaced from the source. The source was typically  $^{137}\text{Cs}$  which emits  $\gamma$ -radiation with an energy level of 662 keV. The apparatus is provided with a discriminator to distinguish the radiation levels received by the 35 detectors. The high energy radiation is said to result primarily from single Compton scattering events and is indicative of the electron density and hence porosity of the geological formation of the borehole at the location of the sonde. The low energy radiation (below 100 keV) is said to be indicative of photoelectric absorption and multiple Compton scattering. By comparing the

detected high and low energy radiation, an indication can be obtained of the chemical nature of the geological formation.

According to the present invention we provide apparatus for determining the density profile of a medium comprising an elongated member containing a plurality of sources of collimated beams of  $\gamma$ -radiation of characteristic energy level below 100 keV disposed as an array along at least part of the length of the member, and a  $\gamma$ -radiation detector associated with each beam and shielded from said sources, and in which apparatus there is at least one detector between each source, each of said collimated beams is directed to irradiate a region external to said member, and the detector associated with that beam is disposed to detect radiation scattered from said region by the aforesaid medium.

In the present invention a low energy ionising radiation source, e.g.  $^{241}\text{Am}$  which emits  $\gamma$ -radiation with an energy level of about 60 keV, is employed. The use of a low energy level source is desirable as it enables cross-talk, i.e. a detector detecting radiation scattered from a radiation beam other than that intended, to be minimised since the effective range from which back-scattered radiation can be detected decreases as the energy level decreases. Thus if higher energy sources are employed, the radiation will penetrate a greater distance into the medium and be back-scattered therefrom with a greater risk that a detector will detect radiation back-scattered from a region irradiated by a beam not associated with that detector. Likewise the use of a low energy source reduces cross-talk resulting from multiple reflections.

The elongated member is preferably a tube of radiation transparent material and is preferably disposed substantially vertically in the medium whose density is to be monitored. However, greater precision may be obtainable if the tube is inclined to the vertical. Conveniently the elongated member is provided with a suitable mounting means and extends down through a suitable port in the roof of the vessel in which the medium is located. Since only a single elongated member has to be employed, the port can be any that is of diameter greater than that of the elongated member. The latter typically has a diameter of not more than about 50 mm.

The sources and detectors are arranged along the length of the elongated member over which the density profile is to be determined. It will be appreciated that it may not be necessary to monitor the density over the whole length of the elongated member since part thereof may always be disposed in a medium of substantially constant density, e.g. in an air space at the upper part of the vessel containing the medium. Indeed if the device is employed to detect the location of phase boundaries, the sources and detectors need only be disposed at those locations along the length of the elongated member encompassing the expected phase boundaries.

It will likewise be appreciated that only that part of the elongated member containing the sources and detectors need be made of a radiation transparent material such as titanium. The remainder of the elongated member may be constructed from a cheaper material such as steel.

The spacing of the sources and detectors depends upon the precision with which it is desired to monitor the density profile. Typically the detectors and sources are sized and spaced so that the density is effectively monitored at intervals 2 to 6 cm.

Each beam of radiation has a detector associated therewith. In one form of the invention, each source provides one beam, preferably directed substantially at an angle of 90° to the longitudinal axis of the tube. Alternatively, in the interests of economy, each source provides two beams, directed in different directions. In that case there will therefore be two detectors for each source. Each source thus has at least one detector associated therewith and there is at least one detector between each source. Where each source provides two beams, one beam is preferably directed upwardly and the other downwardly, each at an angle in the range 30° to 80° to the longitudinal axis of the tube. If the angle is too small, there is a risk that the radiation will be reflected from the inner surface of the tube rather than being back-scattered from the medium outside the tube. To minimise cross-talk, it may be desirable to have adjacent beams directed in different radial directions.

The sources are preferably pellets of the radioactive material disposed in bores drilled in a block of a suitable radiation opaque material such as tungsten. The length and diameter of the bores determines the degree of collimation of the beams.

The detectors are shielded from direct radiation from the sources by means of a suitable radiation opaque material such as tungsten.

The invention is of particular utility in determining the density profile, and hence the location of phase boundaries in an oil/water/gas separator. In addition to determining the location of gas/oil and oil/water interfaces, boundaries between oil and oil/water emulsions and/or between liquid and foam regions can be determined. Also the feed to an oil separator may contain some solids such as sand and/or heavy hydrocarbons, e.g. asphaltenes, and the boundary between such phases and liquid phases can also be detected.

Therefore we also provide an oil separator comprising a vessel provided with an inlet port for feeding an oil/water mixture into a separation zone wherein the oil/water mixture separates into an oil phase above a water phase, a weir disposed such that the oil phase can flow over the weir into an oil outlet zone, an oil phase outlet port communicating with the oil outlet zone, a water phase outlet port disposed to remove the separated water phase, and a probe comprising a density profiler probe in accordance with the invention disposed in said vessel, said probe having at least an array of sources and detectors spanning the interface between the oil phase and the water phase and, preferably, also an array of sources and detectors spanning the upper surface of the oil phase.

The invention is further illustrated by reference to the accompanying drawings wherein:

Figure 1 is a vertical section through part of a density profiler in accordance with the invention,

Figure 2 is a section along the line II – II of Figure 1,

Figure 3 is a vertical section through an alternative source arrangement, and

Figure 4 is a diagrammatic elevation of apparatus in combination with an oil/water separator.

In Figures 1 and 2 there is shown part of a profiler in accordance with the invention. The 5 profiler has an outer tube 10, typically of 50 mm diameter, formed from a radiation transparent material such as titanium, and is divided into two longitudinally extending compartments 12, 14 by a chordal strip 16 of a radiation opaque material such as tungsten. The tube is mounted substantially vertically in a vessel, e.g. an oil separator, containing the medium whose density is to be profiled, by means not shown which also serve to seal the tube to a port in the vessel.

10 The larger compartment 12 is provided at vertically spaced intervals with blocks of a radiation opaque material such as tungsten extending across the diameter of the tube. A sequence of three such blocks are shown in Figure 1 where the blocks are designated 18, 20 and 22. Each block has a hole 24 bored diametrically therethrough inclined at an angle, typically in the range 30 to 80°, to the longitudinal axis of the tube. Located in the centre of 15 each hole 24 is a pellet of a source 26, such as  $^{241}\text{Am}$ , of low energy  $\gamma$ -radiation. The walls of the holes 24 collimate the radiation into diametrically opposed, inclined, beams which penetrate the wall of tube 10 into the medium outside the tube 10. The beams from the source in block 20 are designated by reference numerals 28a and 28b. The "spread" of beam 28a is indicated by the dotted lines 30.

20 Located above and below each of the blocks are radiation detectors. Each detector is typically a sodium iodide crystal linked to a GM tube. The detector located above block 18 is designated 32, while the detectors below and above block 20 are designated 34 and 36 respectively. The detector below block 22 is designated 38. The detectors are shielded axially from radiation from the source by their associated blocks, and by radiation opaque members 25 40, 42 disposed between detectors 32 and 34 and between detectors 36 and 38 respectively.

As shown in Figure 2, the detectors are also shielded radially from radiation by shielding member 44 extending round part of the interior wall of tube 10 and the longitudinally extending strip 16. The shielding member 44 does not extend all round the interior wall of the 30 compartment 12, but leaves a "window" through which radiation can reach the detector from outside the tube. Each detector and its associated window are positioned so that the detector can detect radiation back-scattered from the medium irradiated by the beam associated with that detector. Thus detector 36 is arranged to detect radiation back-scattered from the region of the medium irradiated by beam 28a, and detector 34 detects the radiation back-scattered from the region of the medium irradiated by beam 28b.

35 The compartment 14 in the tube provides a conduit for cabling (which may be electrical or fibre-optic) as required to connect the detectors to external data logging equipment.

The detectors and the shielding should be arranged such that the detector detects little or no radiation from regions irradiated by beams other than the one associated with that

detector. Such cross-talk is minimised by the use of relatively low energy sources. Thus with sources having an energy level below about 100 keV, detected back-scattered radiation is unlikely to be derived from scattering at a distance more than about 10 cm from the detector, and likewise the radiation is unlikely to penetrate into the medium to a distance more than 5 about 10 cm from the source. In Figure 1 the extent of the penetration is given approximately by the dotted lines 46, 48, while lines 50, 52 indicate the approximate location of adjacent vertically disposed detection levels. The distance between lines 50 and 52 represents the vertical resolution of the profiler.

In Figure 3 an alternative embodiment is illustrated. Two collimated beams are provided 10 by a single source 26 disposed at the bottom of a pair of intersecting bores 24a, 24b in the block 20 of radiation opaque material. The beams are thus directed upwardly and downwardly at an angle to the longitudinal axis of the tube but in this case the beams can be directed in the same radial direction. This arrangement may have constructional advantages in that the detectors may be aligned and located on a common elongated circuit board.

15 In Figure 4 there is shown in section an oil/water separator vessel 54 provided with an inlet port 56 to which a mixture of oil and water to be separated is supplied, a weir 58, and outlet ports 60, 62 from which separated water and oil phases are removed from the vessel. A gas vent (not shown) may also be provided.

The supplied oil/water mixture initially tends to form a foam region 64 adjacent the inlet 20 port 56. This gradually collapses forming an oil/water emulsion region 66 which separates with time into an oil phase 68 and a water phase 70. The oil phase spills over the weir 58 into an oil outlet zone 72 from which the oil phase is removed through outlet port 62. The water phase is removed through outlet port 60.

It is desirable to maximise the throughput. However, there is a risk that if the oil/water 25 mixture is fed too fast, the separation will be insufficiently complete and the foam layer and/or the emulsion may reach one or both of the outlet ports. It is generally not practical to monitor the boundaries of the phases by optical means, e.g. sight glasses, and so to monitor the location of the phase boundaries, a probe 74, constituting apparatus in accordance with the invention, is deployed vertically through a port 76 in the roof of the vessel 54.

30 The probe 74 is a hollow tube in which, for parts of its length, are mounted arrays of sources and detectors as shown in Figure 1. The probe has two separate arrays, one spans the oil/gas interface while the other array spans the oil/water interface. Each array is of sufficient length to embrace the range of heights in the vessel where that interface is liable to occur. Each array comprises a plurality, for example 5 or more, of the sources and detectors.

35 Electrical circuitry, not shown, is connected to each detector to provide signals indicative of the amount of radiation received by the detector.

By calibration, it is thus possible to determine whether the medium in the space between the transducer and the reflector is oil, water, gas, or mixtures thereof, e.g. a foam or an

emulsion. By recognising that the nature of the medium at the level of one transducer is a certain phase and that the medium at the transducer next above the one transducer is a different phase, it is self evident that the phase boundary lies at a level between the levels of the two transducers.

Claims

1. Apparatus for determining the density profile of a medium comprising an elongated member containing a plurality of sources of collimated beams of  $\gamma$ -radiation of characteristic energy level below 100 keV disposed as an array along at least part of the length of the member, and a  $\gamma$ -radiation detector associated with each beam and shielded from said sources, and in which apparatus there is at least one detector between each source, each of said collimated beams is directed to irradiate a region external to said member, and the detector associated with that beam is disposed to detect radiation scattered from said region by the aforesaid medium.
2. Apparatus according to claim 1 wherein each source is located in a hole in a block of radiation opaque material, said hole extending diametrically across the elongated member and being inclined to the longitudinal axis of the elongated member at an angle in the range 30 to 80°.
3. Apparatus according to claim 1 or claim 2 wherein each source gives two diametrically opposed collimated beams of radiation and there are two detectors, shielded from each other, between each source.
4. Apparatus according to any one of claims 1 to 3 wherein the source is  $^{241}\text{Am}$ .
5. Apparatus according to any one of claims 1 to 4 wherein the elongated member has a diameter not exceeding 50 mm.
6. A method of determining the density profile of a medium comprising projecting into said medium a plurality of collimated beams of  $\gamma$ -radiation of characteristic energy level below 100 keV from an array of sources linearly disposed along at least part of an elongated member extending through at least part of said medium, and determining the amount of  $\gamma$ -radiation scattered by said medium from each of said beams by means of detectors being disposed along said member, there being a detector associated with each beam.
7. An oil separator comprising a vessel provided with an inlet port for feeding an oil/water mixture into a separation zone wherein the oil/water mixture separates into an oil layer above a water phase, a weir disposed such that the oil phase can flow over the weir into an oil outlet zone, an oil phase outlet port communicating with the oil outlet zone, a water phase outlet port disposed to remove the separated water phase, and a probe

- comprising apparatus as claimed in any one of claims 1 to 5 disposed in said vessel,  
said probe having at least an array of sources and detectors spanning the interface  
between the oil phase and the water phase.
8. An oil separator according to claim 7 wherein the probe has an array of sources and  
detectors spanning the upper surface of the oil phase.

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Fig.1.

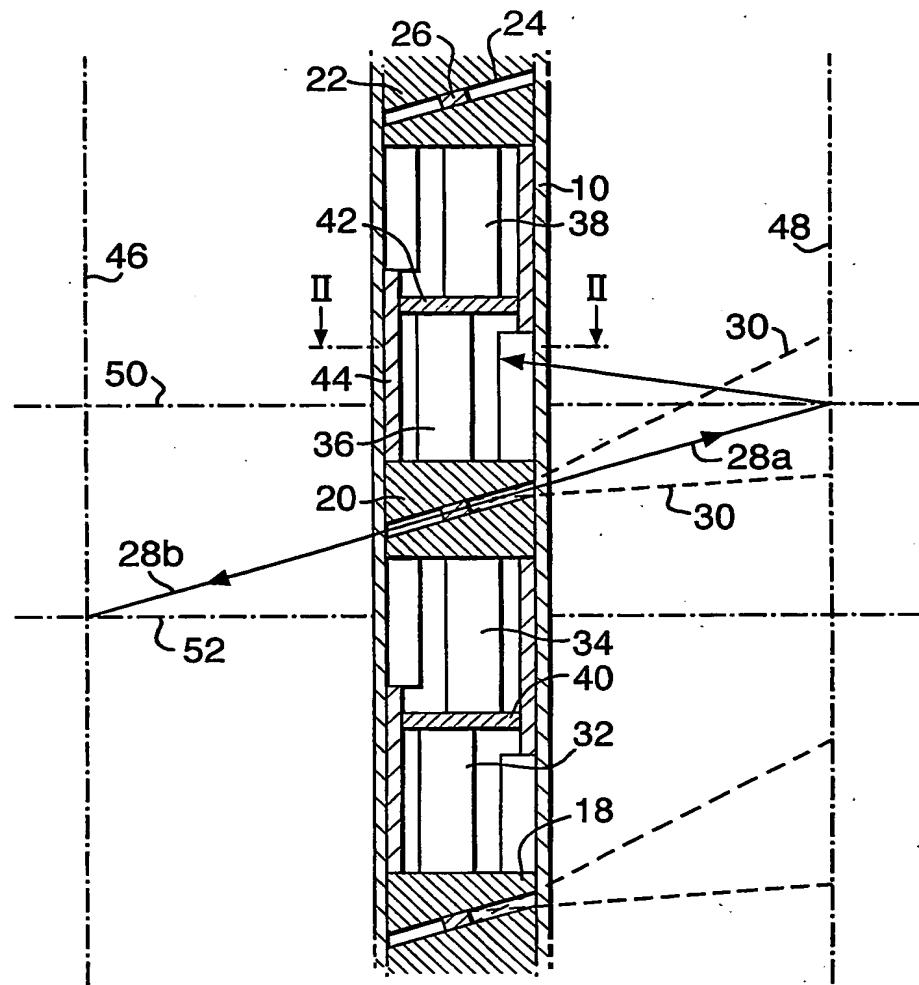


Fig.2.

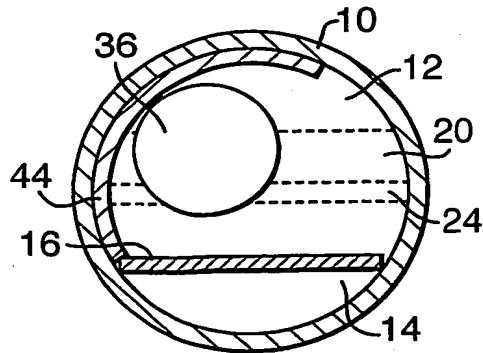
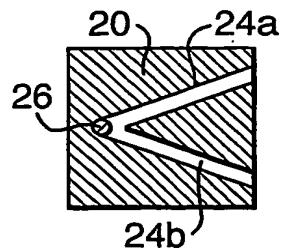


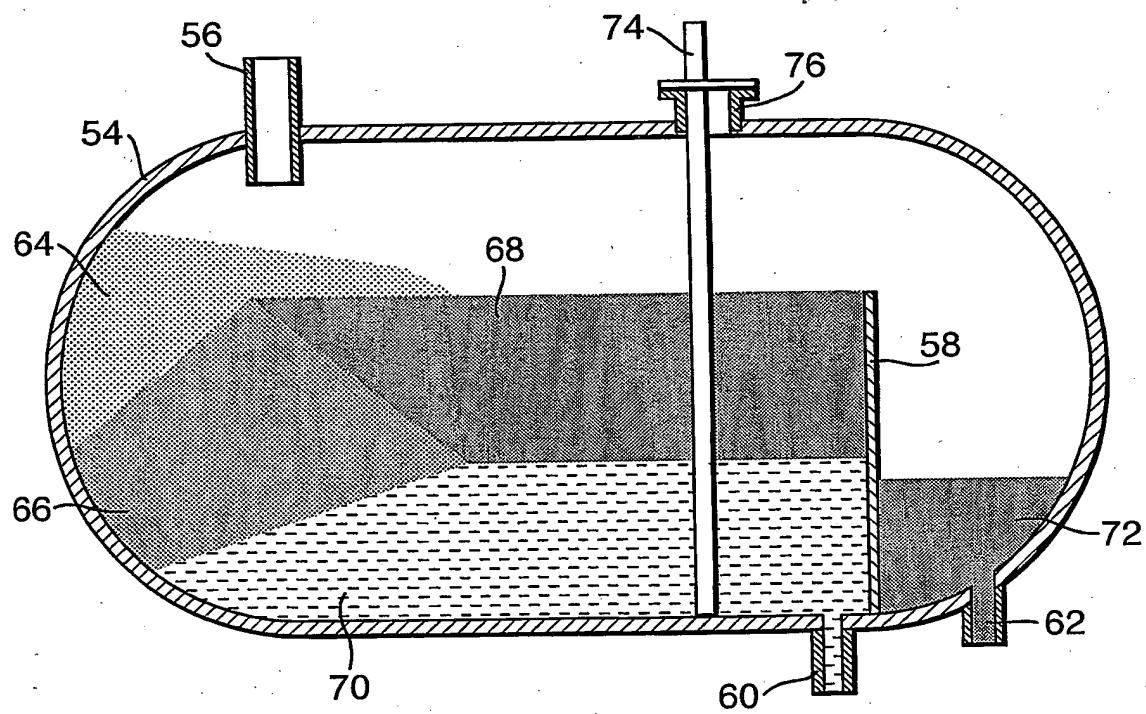
Fig.3.



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Fig.4.



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## INTERNATIONAL SEARCH REPORT

International Application No

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**A. CLASSIFICATION OF SUBJECT MATTER**  
 IPC 7 G01F23/288 G01N23/203 G01N9/24

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**Minimum documentation searched (classification system followed by classification symbols)  
 IPC 7 G01F G01N G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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Y	WO 00 22387 A (ICI PLC ;JACKSON PETER (GB); KNAPP ROBERT SIMON (GB)) 20 April 2000 (2000-04-20) cited in the application page 5, paragraph 2 -page 7, paragraph 2; figures 2,4 ---	1-8
A	US 4 661 700 A (HOLENKA JACQUES M) 28 April 1987 (1987-04-28) cited in the application the whole document ---	1-8 -/-

 Further documents are listed in the continuation of box C. Patent family members are listed in annex.

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## INTERNATIONAL SEARCH REPORT

International Application No  
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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2 378 219 A (HARE DONALD G C) 12 June 1945 (1945-06-12) the whole document	1-8
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